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Refractive Index Sensing by High Aspect Ratio Titanium Nitride Trench Structures

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Abstract: Titanium nitride grating structures are fabricated by a combination of deep reactive ion etching and atomic layer deposition. Such structures being analyzed as an ambient medium sensor, exhibit the refractive index sensitivity of 430 nm/RIU.    2018 The Author(s)

OCIS codes: (050.1950) Diffraction gratings; (250.5403) Plasmonics; (160.4760) Optical properties; (240.0310) Thin films; (220.4241) Nanostructure fabrication; (280.4788) Optical sensing and sensors

Plasmonics, a field of nanophotonics where surface plasmons, collective oscillation of electron density, play a key role to confine light at the nanoscale, find promising applications in sensing [1]. Such plasmonic sensing devices have been developed to localize electric fields in very confined volumes close to the metal surfaces, thus tracing very small amounts of analytes in label-free biosensors. Grating sensors made of plasmonic (with a negative permittivity) [2] or dielectric [3] elements have been extensively studied for their potential of multiplexing of sensing units, achieving high throughput integration on lab-on-a-chip systems. They can contribute to design and production of point-of-care (POC) devices for swift, facile, and inexpensive diagnosis in future health care. Sensing elements, in general, require high robustness and stability, since, in many cases, they should sustain hours of continuous measurements, as well as made of cheap and abundant materials.

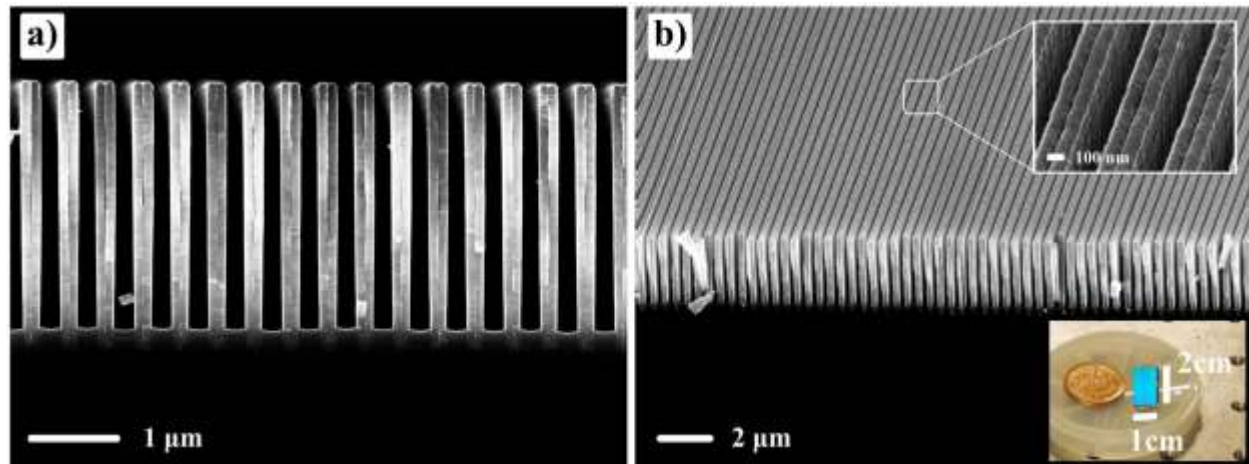


Fig. 1. Scanning electron microscopy images of the fabricated TiN trench structures. (a) cross section and (b) bird-eye-view (insets above and below show zoomed image of the top part and the photo image of the actual sample, respectively).

Here, we characterize the sensitivity of titanium nitride (TiN) high aspect ratio grating structures towards the refractive indices of different ambient liquids aiming for potential biosensing applications. TiN is a highly-refractory material that exhibits a plasmonic response in the visible and near-infrared (IR) wavelengths [4]. TiN is more abundant and cheaper than noble metals such as Au, and offer the possibility of tuning its permittivity by varying deposition conditions and post-treatment. Moreover, TiN films can be deposited by the atomic layer deposition (ALD) technique, enabling conformal deposition of plasmonic and dielectric layers with nanometer precision and as a consequence realization of large-scale metamaterial structures with exceptional uniformity in large areas [5].

Our TiN-based trench structures were realized by the combination of ALD with advanced deep reactive ion etching. The fabrication procedure is based on ALD deposition of TiN films on sacrificial Si templates with sub-sequential removal of Si. TiN is deposited at 500  C on a silicon trench template with the pitch of 400 nm and height of around 2.7  m. Silicon between vertical TiN layers is selectively etched to fabricate the high aspect ratio TiN trenches. Permittivity of TiN films with various thicknesses of 18 - 105 nm and post-annealing temperatures of 700 -

900°C is characterized by an ellipsometer. We found that the highest annealing temperature of 900°C gives the most pronounced plasmonic properties with the highest plasma frequency, $\omega_p = 2.53$ eV ($\lambda_p = 490$ nm) for the thickness of 105 nm.

Grating structures can exhibit a sharp spectral increase in reflection, which is referred to as the Rayleigh-Woods anomaly (RWA) [6-8]. The spectral position of the reflection peaks associated with the RWA shifts depending on the changes in refractive indices of the surrounding media. We characterized the reflection peak associated with the RWA for different liquids, such as distilled water (DI), ethanol, and isopropanol (IPA). The bulk refractive index sensitivity of our sensing unit turns out to be 430 nm/RIU.

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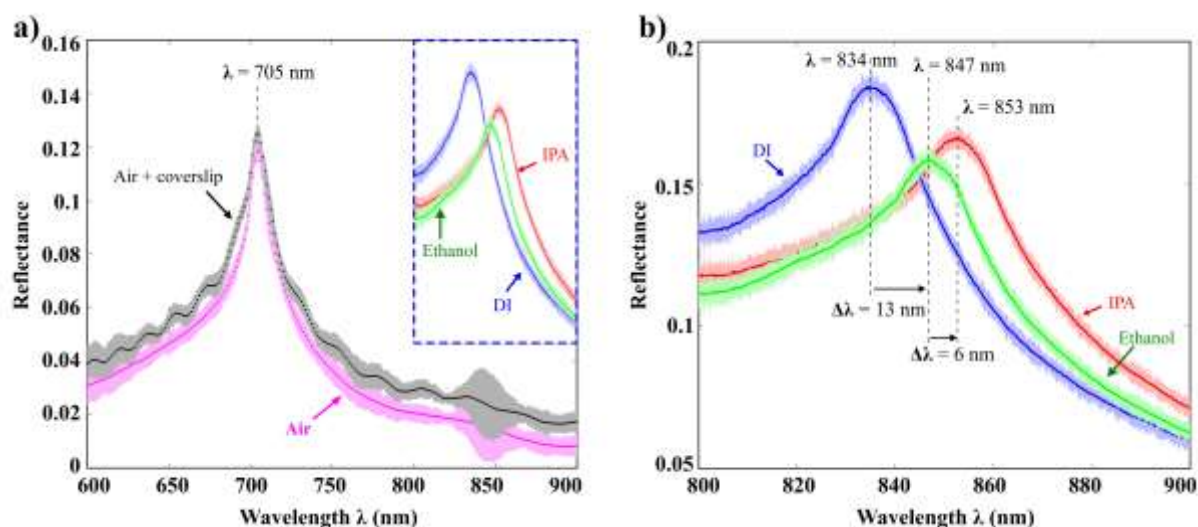


Fig. 2. Measured reflection from the TiN trench structures for different analytes such as air, distilled water (blue), ethanol (green), and isopropanol (red) in the wavelength range of (a) 600 - 900 nm and (b) 800 - 900 nm. Note that the dashed square in (a) corresponds to (b). Refractive indices of distilled water (DI), ethanol, and isopropanol (IPA) are 1.327, 1.354, 1.371 in the wavelength region of interest, respectively.

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